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SERI/PR-35-228

April 1978

Technology Crosscuts for BES Critical Research Needs for Solar Technology Development

Solar Energy Research Institute
A Division of Midwest Reseach Institute

1536 Cole Boulevard
Golden, Colorado 80401

Operated for the
U.S. Department of Energy
under Contract No. EG-77-C-01-4042

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PREFACE

This progress report summarizes SERI's preliminary identification of basic research needs which are important to the success of solar technology development. This identification is a part of SERI's assignment under the "Technology Crosscuts for BES" study requested by letter to Dr. Paul M. Rappaport, Director of SERI, from Dr. James S. Kane, Associate Director for Basic Energy Sciences, Office of Energy Research, on January 23, 1979.

Comments and suggestions are encouraged. They should be directed to the appropriate SERI task representative:

T. S. Jayadev (Chairman, Natural Sciences) - Solid State Physics
- Engineering, Mathmatics, and Geoscience
- Advanced Energy Projects

David Benson (Vice Chairman) - Metallurgy and Ceramics
John S. Connolly and Thomas A. Milne - Chemical Sciences
Michael Seibert and Ruxton Villet - Biological Energy Research
Albert Czanderna - Materials Chemistry
J. David Roessner (Chairman, Social Sciences)
Bert Mason - Behavioral and Social Sciences

TSJayadev
T. S. Jayadev
Task Co-Leader

J. David Roessner
J. David Roessner
Task Co-Leader

Approved for:

SOLAR ENERGY RESEARCH INSTITUTE

for
J. C. Grosskreutz
Assistant Director, Research

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SECTION 1.0

INTRODUCTION

Successful development and utilization of solar technologies requires simultaneous achievement of cost, efficiency, reliability, durability and safety goals which other technologies have achieved only after many decades of evolution. Accelerating this process for solar energy will require extensive and carefully focused R & D. The purpose of SERI's participation in the Technology Crosscuts study is to identify key research needs which should be met in order to reduce technical barriers to successful development and commercialization of solar energy conversion systems.

The emphasis of our approach is on research which contributes to fundamental understanding. Such research is not necessarily solar-specific. The selection of critical research issues for the solar program is based on our present perception of promising solar energy conversion concepts and known or projected impediments to their commercial realization.

This progress report is largely based on viewpoints and opinions solicited by SERI from key scientists around the country.* The majority of these scientists are not solar technology experts, but they are experts in specific disciplines upon which the development of solar technologies depend; for example, high temperature ceramics, photosynthesis, semiconductor device physics, etc. The participating SERI staff have superimposed a solar perspective upon these specialists' recommendations.

This report is organized in sections corresponding to Divisions of Basic Energy Sciences. Each section is a self-contained, condensed summary of many expert opinions. Detailed amplifications will be provided to augment this preliminary discussion in a later report (June 1979).

No attempt has been made to set any priorities for the identified research needs.

* Participants are listed in Appendix B.

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SECTION 2.0

RESEARCH ISSUES AND NEEDS

2.1 CHEMICAL SCIENCES

2.1.1 Thermal Conversion of Biomass

The thermal processing of biomass, though centuries old, can profit from an infusion of basic research as highly efficient conversion to high value fuels and chemical feedstocks is sought. Identified research needs are:

- development of thermodynamic property information for cellulose, lignins and hemicelluloses;
- methods of depolymerization of lignin which are analogous to hydrolysis of cellulose;
- detailed studies of prototype gasifier reactors to understand the mechanisms and kinetics of reactions;
- fundamental understanding of slow and fast pyrolysis as influenced by temperature, pressure, physical state and reactant gases (particularly H_2 and steam);
- characteristics and properties of pyrolysis liquids;
- studies of toxicity of pyrolysis products;
- oxidation of biomass or its derivatives directly in fuel cells; and
- novel catalytic gasification and liquefaction schemes.

2.1.2 Thermochemical Conversion of Solar Energy

Specific research needs in this category include:

- thermochemical water-splitting research, matching the chemical processes to solar heat delivery characteristics;
- new processes for high temperature extractive metallurgy;
- process chemistry and kinetics in chemical heat transport and storage (e.g., behavior of latent heat storage materials);
- direct N_2 fixation chemistry;
- general support of energy related high-temperature chemistry, including thermodynamics data acquisition and critical evaluation (especially for materials with variable stoichiometry; and

- new chemical syntheses using high temperature plus photolysis and rapid quenching.

2.1.3 Solar Electrochemical Conversion

The entire area of heat-driven electrochemical conversion deserves renewed support to consider the opportunities presented by solar heat sources. Specific suggestions of research needs include:

- basic work on thermally regenerable emf cells, including aqueous and nonaqueous concepts for both high- and low-temperature heat sources;

- search for new solid electrolytes to compete with beta-alumina, including anion as well as cation conductors;

- fundamental microscopic description of the ionic and electron processes at solid/electrolyte interfaces;

- utilization of ceramic (ZrO_2) oxygen ion conductors as solid electrolytes for the high temperature electrolysis of steam or carbon dioxide; and

- use of thermionic diodes for d.c. power production (for the electrolysis of water to H_2, for example).

2.1.4 Photochemical Conversion

Unlike photobiology and photoelectrochemistry, there does not yet exist an operable, synthetic photochemical system with performance in need of improvement or with mechanisms in need of understanding. On the other hand, there is more flexibility with purely chemical systems and thus greater opportunity to invent new systems and to assemble and "tune" the components to specific requirements.

Research opportunities include:

- photocatalytic water splitting and reduction of CO_2 and N_2 via multi-photon, multi-electron redox processes in homogeneous and heterogeneous systems;

- chemical synthesis (organic, inorganic, organometallic and polymer) to obtain coupled photochemical and catalytic systems tailored specifically to achieve efficient energy conversion and storage; quantum efficiencies of wasteful and degradative steps must be minimized;

- systematic photophysical and photochemical studies of organized molecular assemblies (e.g., membranes and colloids) as models for both natural and synthetic conversion schemes; and

- applications of new instrument techniques (e.g., nonlinear spectroscopy, light-excited magnetic resonance, small-angle neutron scattering, solid-state nmr) to relate structural data to photochemical properties; development of new instrumentation (e.g., subpicosecond absorption and fluorescence spectroscopy at low light levels).

Gaps exist in the fundamental understanding of:

- spectroscopic and photophysical parameters of chlorophylls and other light-absorbing molecules;
- theoretical and experimental bases for controlling the mechanisms and rates of energy- and electron-transfer processes (realistic theoretical models of solar efficiencies of photochemical reactions are needed); and
- theory which is capable of providing accurate, quantitative predictions of spectroscopic, photophysical, photochemical, electrochemical and catalytic properties of molecules in their ground- and excited electronic states.

2.1.5 Solar Photoelectrochemical Conversion

Much basic research is needed to assess the potential of semiconductor-electrolyte systems to dissociate water or drive other chemical reactions. Some specific research needs include:

- develop better basic understanding of photo-induced charge transfer at semiconductor-electrolyte interfaces;
- confirm and explore significance of recently proposed "hot carrier" injection model;
- develop better basic understanding of overvoltage requirements for semiconductor electrodes and nature of catalytic effects at semiconductor surfaces;
- develop better basic understanding of electronic energy levels of liquid electrolytes at semiconductor surfaces with regard to solid state energy bands (in particular, energy levels associated with intermediate steps of redox reactions at electrode surfaces);
- conduct basic research on new nonaqueous electrolytes;
- develop valid theoretical models for semiconductor electrodes which permit *a priori* prediction of conversion efficiency, stability, and current-voltage characteristics; and
- investigate basic chemistry of semiconductor surfaces to establish the potential scope of surface chemical modification.

2.2 BIOLOGICAL ENERGY RESEARCH

2.2.1 Biomass

There is a need for research in the three related disciplines of genetics/microbiology, biochemistry, and biochemical engineering. The ultimate objective of this work is to produce fuels and chemical feedstocks efficiently.

2.2.1.1 Genetics and Microbiology

Apart from the more conventional techniques of strain selection and induced mutagenesis, the newer methodologies of genetic engineering (e.g., recombinant DNA work) must be exploited. In addition to working on pure strains of microorganisms there is a need to study interactions in mixed cultures. Recommended areas of research including both microbial and plant species are:

- develop strains of microorganisms for converting cellulose, lignin and hemicellulose efficiently to fuels and commodity chemicals;
- develop thermo-tolerant and product-tolerant microbial strains that would lead to improved bioreactor efficiency;
- investigate microbial ecology (important in development of anaerobic digestion processes);
- study microbial and plant production of hydrocarbons;
- investigate selection and agronomic development of energy crops; and
- study tissue culture development and genetic manipulation of plant cells to produce biomass at high rates and metabolites as fuels and chemical feedstocks.

2.2.1.2 Biochemistry

An understanding of biosynthetic pathways and the molecular mechanism of enzyme action in these pathways would permit effective manipulation to produce fuels and chemicals. Such studies would include:

- the molecular mechanism of cellulase production and action, which is not yet understood;
- studies of biosynthetic pathways which can be directed toward homofermentative modes;
- identification of enzymes specific for lignin conversion;
- work on xylanases;

- work on pentose metabolism;
- isolation and immobilization of enzymes;
- membrane biochemistry related to product tolerance and microbial surface attachment;
- studies of metabolic regulation in higher plants and possibilities for manipulation; and
- study of the biochemistry and physiology of water use by plants.

2.2.1.3 Biochemical Engineering

In this area fundamental work in biological science can find its biotechnological expression. There is a need for a greater fusion of biological research work with that in chemical engineering.

- develop novel bioreactors to accommodate insoluble substrates;
- develop immobilized-cell bioreactors;
- study the dynamics of bioconversion processes to obtain bioreactor design information;
- study the fluid dynamic behavior of slurries in high concentration;
- improve the conventional and devise novel separation processes (conventional distillation is not energy-efficient);
- investigate chemical and physical pretreatment of lignocellulose for more rapid conversion; and
- study bioprocess control and optimization.

2.2.2 Photobiology

Photobiological conversion of solar energy includes those quantum conversion processes which organisms use to drive metabolism. Such processes can, in principle, be adapted to produce alternative forms of energy directly. At the present time applied research is incipient, but the following basic research areas are evident:

- the primary photochemistry of photosynthetic (chlorophyll, bacteriochlorophyll) and purple membrane (bacteriorhodopsin) systems including manipulation of the size of antenna pigment complexes;
- biological photovoltaics (or solar batteries);
- stability of the photosynthetic apparatus *in vitro*;

- nitrogen and hydrogen metabolism in photosynthetic (particularly marine) organisms, including genetic and biochemical work to modify and enhance photosynthesis, to stabilize enzymes, and to allow for hydrogenase and nitrogenase activity under aerobic conditions;

- *in vitro* coupling of photosynthetic components to produce H_2 or NH_3; and

- carbon metabolism (C_3, C_4, CAM) and photorespiration, which could lead to improved biomass production and organisms which produce useful hydrocarbons.

Many of these studies could lead to prototype microbial and *in vitro* energy producing systems. In addition, such knowledge and experience would be essential for the design and development of artificial chemical systems which would mimic natural systems. An example is the synthesis of an artificial photochemical "reaction center," which might be coupled to electrodes to produce electricity or used in other systems to produce H_2 or reduced carbon substances.

The most serious gap in fundamental knowledge within these areas involves the lack of understanding of biological mechanisms. Examples are:

- primary photosynthesis -- the relationship of structure and function;

- the mechanism of O_2 evolution (i.e., water splitting);

- the stability of enzymes -- for example, why some Fe/S proteins are stable and others are not;

- O_2 sensitivity of hydrogenase and nitrogenase;

- regulation of biological systems; and

- H_2 evolution from photosynthetic bacteria (knowledge in this area could lead to applications on a relatively short-term basis).

2.3 MATERIALS SCIENCES

The most critical issue regarding a material's use in a solar energy conversion system is its impact upon life cycle systems' cost and performance and the consequent impact on the cost of energy provided by the system. In a study for the Office of Technology Assessment [1], the Federation of Materials Societies* identified costs of materials and materials reliability as major

* The FMS is composed of the following societies: American Ceramic Society, American Chemical Society, American Institute of Chemical Engineers, American Institute of Mining Metallurgical and Petroleum Engineers, American Society for Metals, American Society of Nondestructive Testing, Institute of Electrical and Electronic Engineers, National Association of Corrosion Engineers, Society for the Advancement of Materials and Process Engineering, Society of Automotive Engineers, Society of Manufacturing Engineers, and the Society of Plastics Engineers

issues in solar technologies. Similar but much more detailed conclusions were reached by more than 200 materials scientists participating in a recent SERI-sponsored workshop on materials research needs in solar technologies [2]. The recommendations included here are based on workshop conclusions and interviews with additional scientists.

Many of the materials performance requirements for solar energy conversion systems are similar to requirements of other engineering systems. However, certain aspects of solar energy conversion systems are uniquely demanding on materials, particularly when low cost and long lifetime constraints are also to be met. Most materials in solar systems are subjected to sunlight, weather, dirt and dust, and diurnal (or more frequent) thermal cycles. Under these adverse conditions, they must continue to perform efficiently with little or no maintenance for 20-30 years. The research needs discussed below address both general and solar-specific materials limitations. All, however, are thought to be important research topics in which advances would significantly benefit solar energy conversion technologies.

2.3.1 Metallurgy and Ceramics

Solar thermal applications require ceramics and metals to operate under stress in fluctuating high temperatures and in a variety of environments depending upon the purpose and design details of the system. In all cases, two common and related concerns are corrosion (including oxidation) and fracture (including creep fatigue, static fatigue, corrosion fatigue, stress-corrosion cracking, creep rupture, and thermal shock fracture). Serious gaps exist in our fundamental understanding of these degradation processes, and basic research is required to:

- develop a better understanding of the atomistic mechanisms occurring at the tip of a growing crack, and particularly the mechanisms by which the chemical environment in the crack affects its growth; and to

- develop methods (for example, computer models) that are capable of predicting complicated chemical reaction processes in multiphase, multicomponent systems using available (partial) thermodynamic information.

New materials may be required to meet some of the more stringent demands of solar conversion systems. Certainly a better understanding of processes of fabrication would help us to make better use of existing materials. Fundamental gaps exist in our knowledge of metals and ceramics processing, and research is required to:

- understand the kinetics of nucleation, phase transformation and solidification (particularly, rapid solidification to form amorphous materials); and to

- understand the behavior of fine particles and how their size, shape, and surface properties affect their rheology and subsequent ceramic and powder metallurgy fabrication.

The adhesion of materials is important in several aspects of solar technology--the undesirable adhesion of dust particles to glass mirrors and glazings, the desirable adhesion of reflective metal coatings to mirrors, the electrostatic bonding of glass encapsulants to semiconductor photovoltaic cells, and the adhesion of protective polymer coatings to various components. All of these applications depend upon the poorly understood phenomenon of adhesion, and research is required to:

- improve the theoretical basis for understanding the atomistic forces involved in adhesion and related interface phenomena involved in removing adhering particulates (for example, the zeta potential concept applied to the formulation of cleaning solutions).

2.3.2 Materials Chemistry

The major research needs in materials chemistry to devise materials preparation and fabrication processes that yield the desired properties (chemical, mechanical, and electronic) are: to understand the structure, bonding, and composition that provide stability; to elucidate mechanisms of degradation in solar-stressed environments in order to guide modifications of metallic, ceramic, polymeric, and semiconductor materials to reduce or eliminate the detrimental reactions; and to use or devise experimental techniques to determine the changes in the important physical properties.

Research on preparing materials includes studying the effects on the desired properties of growth or modification processes of thin films, coatings, glassy materials, and crystalline materials. For example, will a sputter deposited thin film modified by ion implantation yield a corrosion resistant material?

Research on the structural, bonding, and compositional relationships must be carried out to understand the properties and stability of polycrystalline materials. Thus, the detailed atomic relationships at the solid/solid interface, such as the segregation and diffusion in grain boundaries and the influence of interfacial effects on the optical properties of alloy reflectors, need to be addressed experimentally. Theoretical models need to be developed on carefully chosen polycrystalline systems that permit verification with experimental measurements. The study of interfaces between different materials (example: polymers/metal oxide) is in dire need of theoretical and experimental research.

Changes in materials properties result from degradation reactions in solar stressed environments, and the mechanisms of degradation need to be elucidated. Of particular importance are chemical modifications at the solid-vapor and solid-solid interface at atmospheric pressure. These modifications are caused by numerous factors: cochemisorption processes, corrosion and attack along grain boundaries, photoenhanced degradation of polymeric materials, enhanced degradation rates from concentrated solar fluxes, and other changes in properties of materials caused by concentrated solar radiation, changes in corrosion mechanisms brought about by the daily and annual solar thermal cycles, and changes in the migration of ions in transparent materials subjected to solar stresses.

Confident design life predictions are not presently possible for many solar energy conversion systems for lack of a fundamental understanding of how the kinetics of degradation processes scale with test conditions. In order to permit long life predictions from short-term tests, basic research is required to:

- define the atomistic, rate-limiting steps in corrosion and determine how these steps may be accelerated in abbreviated laboratory tests without altering the basic mechanisms; and to

- devise sensitive instrumentation capable of detecting and measuring the very early stages of a degradation process.

Finally, advanced instrumentation and methods are needed for preparing and modifying new materials, for characterizing the interfacial properties of polycrystalline materials, for measuring the incipient stages of diffusion, segregation, chemisorption and other processes that lead to undesirable changes in the properties of materials, and for measuring properties that are of special interest such as the hemispherical optical properties of solar materials.

2.3.3 Solid-State Physics

Several areas of basic research have been identified as needing additional work to support the development of solid-state solar energy conversion systems.

2.3.3.1 Semiconductor Materials

New materials such as amorphous semiconductors and organic semiconductors are not yet well understood. Studies of their structure and conduction mechanisms are required. Numerous gaps exist in the understanding of the thermodynamic behavior of both amorphous and crystalline semiconductors and particularly at device interfaces such as metal-semiconductor and semiconductor-semiconductor interfaces (for example, the kinetics of compound formation at metal-semiconductor interfaces, and solar radiation effects on electromigration of ions in thin films).

2.3.3.2 Semiconductor Devices

Gaps remain in the understanding of important processes occurring in semiconductor devices. Direct energy conversion processes like thermoelectrics, thermionics, and ferroelectrics are very important to solar energy conversion because breakthroughs in these areas will open up new avenues for utilization of solar energy.

In homojunctions, more research is needed to explain: carrier recombination due to junction field and space charge effects; gap narrowing due to degeneration; Auger recombinations at high generation rates; and the penalties imposed by drift fields.

In heterojunctions, more research is needed to: improve the theory of band interconnection at junctions; model recombinations at interfaces; guide the selection of material combinations to achieve good junctions; and address a number of other gaps in the understanding of the physics of interfaces.

2.4 ENGINEERING, MATHEMATICS, AND GEOSCIENCES

2.4.1 Engineering Research

There is vital need to assist the development of solar technologies by conducting research in engineering sciences. Such research would be designed to generate information on processes or materials or to explore new techniques (for example, studies of chemical reactions assisted by solar energy to accomplish cooling). The emphasis would not be on technology which uses off-the-shelf equipment, but on applied science, which will lay the foundation for future technologies or which provides knowledge and helps to extend the frontiers of present day technology. Thus, the suggestions made here do not overlap with the present programs in the Office of Energy Technology. The following topics have been identified by researchers in solar engineering whom we contacted for this study.

2.4.1.1 Solar Cooling

There exist a number of basic and applied research problems in the area of solar cooling and heat pumps. Examples of such problem areas are endothermic cooling methods, desiccant cooling processes and materials, chemical heat pumps, dehumidification and indirect evaporative cooling.

2.4.1.2 Passive Solar Technology

Data on heat conduction from buildings into soils needs to be accumulated and analyzed to better understand conditions for which passive solar technology can be used. Also, multizone convection remains a complicated problem deserving of advanced mathematical analysis.

2.4.1.3 Solar Ponds

Challenging questions relate to the hydrodynamics of salty solar ponds. The most important of them is stability in a pond subjected to temperature transients and wind disturbances at the surface. Microconvection currents, edge effects, and movement of boundaries between convecting and nonconvecting zones also are of great importance. These subjects are in the area of hydrodynamics and have not been supported by the solar program because the problems identified were not solar-specific.

2.4.1.4 New Concepts for Solar Power Stations

In some circles there is concern that the cost of heliostats may not decrease enough to make solar electricity competitive. New concepts for solar power generation need to be encouraged and explored, more as long-range research than as technology development.

2.4.1.5 Fluid Mechanics

Many of the problems in fluid mechanics identified for other applications also are important for solar technology. There are four areas where basic research is needed: turbulence; multiphase flow; fluid-structure interactions; and boundary layer effects.

2.4.1.6 Heat Transfer

Though this discipline may appear to be mature, in recent years several developments in solar energy conversion have been stymied by the difficiency of knowledge in this area. For example, it has been realized recently that heat loss rates in moving air appear to be very different from previous assumptions.

2.4.2 Mathematics Research

Four areas of mathematics research hold promise for solving problems in solar energy R & D:

- general applied mathematics -- including solutions to ordinary and partial differential equations, integral equations, asymptotic analysis, perturbation theory, inverse problems, potential theory, and variational techniques;
- numerical solutions to differential and integral equations and numerical linear algebra;
- linear and nonlinear optimization techniques and optimal control theory; and
- statistical methods, stochastic processes, and parameter estimation techniques.

The mathematics research community has not been made aware of research needs for solar energy (in contrast to their active participation in other energy technologies). This is an important issue that requires immediate attention. A DOE- and/or SERI-sponsored workshop to define problem areas and potential paths to solutions is strongly recommended.

Some possible research needs were suggested by the research scientists contacted:

- Heat transfer and fluid dynamics problems, including inviscid flow and Navier-Stokes problems, generally require qualitative and quantitative solutions to integral and partial differential equations (both time dependent and steady-state). Mathematical methods such as numerical finite difference and finite element techniques, conjugate gradient techniques, hydrodynamic stability analysis (similar to Bénard convection problems), asymptotic analysis, perturbation theory, and potential theory are required; in many cases they may have to be extended to meet the complexities of the problems.

- Statistical problems (such as requirements to summarize the temporal and spatial variations and correlations between insolation, wind, and temperature) must be solved as parts of the solar energy system siting selection. Mathematical techniques required may include spectral analysis, time series, stochastic processes, covariance techniques, and multiple regression.

- Other problem areas which could benefit from mathematics research include the modeling of photovoltaic device operation, which requires solution of nonlinear, three-dimensional, partial differential equations. Optimization and control problems may require advances in linear and nonlinear programming, integer programming, stochastic optimization techniques, and the Pontryagin Theory of Optimal Control. Similarly, techniques such as Kalman filtering, Luenberger observers, and gradient techniques, which are used in electrical engineering designs, may be needed in solar system modeling and optimization. Computer modeling of solar systems may be made much more efficient by use of appropriate ordinary differential equation solution techniques designed for stiff equations.

2.5 ADVANCED ENERGY RESEARCH PROJECTS

Solar energy conversion technologies presently under development are not so promising that new concepts can be neglected. On the contrary, an aggressive program is needed to stimulate and encourage innovation and introduce flexibility into the DOE solar research program. New concepts are the insurance for society's future energy needs; like life insurance, one does not look forward to having to rely on it but recognizes the need for the investment.

The Advanced Energy Research Projects program should be structured to accommodate new concepts rather liberally and to support the initial phases of research needed to bring these concepts to a decision point.

2.6 BEHAVIORAL AND SOCIAL SCIENCES

"A notable weakness [in DOE research] is the tendency to view obstacles to adoption of new energy systems as purely technological. Important obstacles to the adoption of new energy systems or expansion of existing ones will increasingly be recognized to be to some degree political, sociological, economic, institutional, and environmental in character. Research which could assist in addressing these issues is virtually nonexistent within the DOE" [3].

This finding of an OSTP working group sets the stage for the following brief description of generic areas of need for basic and applied social science research that would support solar energy development. These needs can be addressed through research undertaken in the traditional disciplines of the social and behavioral sciences: sociology, political science, economics, and psychology; and in newer, applied, and multidisciplinary fields such as environmental studies, policy sciences, and law.*

We have organized research needs by area or subject of research rather than by discipline, because in most cases several disciplines have made efforts to address particular gaps in knowledge or types of social or behavior phenomena. For example, even in the case of "basic" research on consumer decisionmaking, psychologists, sociologists, and economists have attempted to develop explanatory and predictive theory. We have not distinguished between basic and applied social science research because such distinctions are both difficult to maintain and likely to be irrelevant for present purposes. Research needs are divided into six categories: Behavior of Individuals; Behavior of Organizations and Communities; Political, Social, and Economic Processes; Social and Economic Feasibility and Impacts; Policy Analysis; and Methodology.

2.6.1 Behavior of Individuals

The basic need in this category of research is improved understanding of the ways in which individual consumers make decisions about durable goods and the factors that influence these decisions. Special emphasis should be placed on energy consumption choices. Specific questions to be answered include:

- tradeoffs among product attributes (cost, performance, reliability);
- improvements upon and expansions of economic decision models;
- influence of risk and uncertainty on consumer decisions;
- interaction of individual decision behavior with other factors such as the marketplace (e.g., resale value of solar homes), locus of responsibility for energy production and consumption (e.g., financing, maintenance);

* Definitions of the social sciences can be found in Appendix A to this document.

- interaction between personal lifestyle and values and energy choices; and
- value and use of information in consumer decisionmaking.

2.6.2 Behavior of Organizations

The basic need here is improved understanding of organizational and community behavior with respect to choices of energy alternatives. Examples of the kinds of organizations and communities of interest are federal, state, and local government units; developers; utilities; community groups; industrial and commercial firms; regulatory agencies. Specific questions to be answered include:

- tradeoffs among product attributes;
- improvements upon and expansions of economic decision models (e.g., development of generic models of utility behavior);
- influence of risk and uncertainty on industry and utility decisions (e.g., expand portfolio theory to include energy decisions);
- value and use of information in organizational and community decisionmaking;
- influence of the environment for decisionmaking (e.g., extent of competition in relevant markets, regulation and taxes, community characteristics, demographics); and
- bureaucratic behavior, with emphasis on the influence of size, structure, objectives, and incentives on decisionmaking.

2.6.3 Political, Social, and Economic Processes

This category of research focuses on the interactions among individuals and groups over time as they both react to and attempt to shape political, social, and economic forces. Specific questions to be addressed include:

- identification of the factors that influence the rate and pattern of diffusion of new technology;
- incorporation of social costs into public decisionmaking (e.g., market and nonmarket failure, role of government in the civilian economy);
- increased understanding of public policy processes (e.g., influence of social and behavioral research in energy policymaking; citizen participation in the technology policy process);
- increased understanding of the impact of energy supply economics on the introduction of new energy technology (e.g., market structure and market power; price, tax, and regulatory policies);

- role of the federal system of government in development and implementation of energy policy (e.g., conflicts in goals among federal, state, and local governments; appropriate responsibilities of the various levels of government);

- social change processes (e.g., predicting changes in fundamental social values such as individual or community control over energy supply; interaction between lifestyles and renewable energy future); and

- improved understanding of relationship between energy production and consumption and the performance of the aggregate economy.

2.6.4 Social and Economic Feasibility and Impacts

Research in this category would focus on identifying and assessing the social and economic impacts of particular energy technologies. Specific questions to be answered include:

- assessing the social and economic impacts of developing alternative energy sources at the regional level;

- predicting sectoral impacts and identifying potential supply bottlenecks of different solar technologies (e.g., raw materials, labor skills);

- identify existing end-use requirements for energy and potential applications for solar technologies (e.g., market analysis, improved matching of end-use needs to primary energy sources); and

- assessment of environmental impacts of solar vs. conventional energy sources (e.g., identify and quantify environmental and health consequences of entire cycle of production and consumption for specific technologies, especially biomass, valuation of environmental impacts).

2.6.5 Policy Analysis

This category of research addresses the problem of choosing courses of government action that are appropriate, effective, and efficient. In this case, the focus is on alternative government actions intended to influence the development and application of energy technologies, particularly solar technologies. Specific questions to be answered include:

- effect of government regulation on technology development and diffusion;

- role of government in developing information as a means of stimulating technology application (e.g., relative emphasis on demonstration projects versus R & D);

- analysis of the influence of policy implementation, in contrast to policy design, on the effectiveness of energy policies;
- increased evaluation of specific programs intended to influence the development and application of solar energy (e.g., National Energy Act, HUD solar heating and cooling demonstration program, state and local incentives);
- impact of regulatory practices of Public Utility Commissions on solar technology utilization;
- effect of tax policy on energy supply and demand; and
- equity consequences of alternative energy technology promotion policies.

2.6.6 Methodology

This category of research concerns the development of new and improved methodological tools to accomplish the research objectives outlined above. Specific needs include:

- survey research methods (e.g., identifying linkages among attitudes, opinions, and behavior);
- increase the multidisciplinary character of existing socioeconomic data bases and models;
- improved program evaluation methods;
- improved energy-economy interaction modeling through better representation of theoretical and empirical relationships;
- improved measures and causal models of social impacts of energy alternatives; and
- expand and update existing industrial sector models (e.g., input-output) to include details of energy use.

SECTION 3.0

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APPENDIX A

DESCRIPTION OF SOCIAL SCIENCE DISCIPLINES

The following description of the five central social science disciplines is taken from Knowledge Into Action: Improving the Nation's Use of the Social Sciences (Washington D.C.: National Science Foundation, 1969).

What Are the Social Sciences?

The social sciences are intellectual disciplines that study man as a social being by means of the scientific method. It is their focus on man as a member of society, and on the groups and societies that he forms, that distinguishes the social sciences from the physical and biological sciences.

Historically, five social sciences have been regarded as central: anthropology, economics, political science, psychology, and sociology. Other important fields that deal with social phenomena are: demography, history, human geography, linguistics, and social statistics.[1]

Anthropology and sociology are somewhat difficult to distinguish from each other. Both study the societies in which man lives, that is, the social forms and structures within which individual and group behavior takes place. Anthropology (which includes social anthropology, archaeology, physical anthropology, and the linguistics of preliterate cultures) studies the varied physical and cultural characteristics of man throughout the world. Traditionally, its attention has been directed to primitive cultures. But a number of anthropologists now study the cultures of industrialized societies, including, of course, the United States; and anthropologists have produced fruitful work on such important contemporary problems as poverty, ghetto life, minority groups, and mental health.

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[1] Branches of psychology and anthropology often fall in the biological sciences as well as the social sciences. Similarly, parts of historical inquiry properly belong in the humanities. We refer the reader to the forthcoming report of the Behavioral and Social Survey Committee for an exposition of the nature of these disciplines, their development, and the kind of work that each does. We also leave to that report the tasks (1) of describing the hybrid fields that exist within the social sciences, and between the social sciences and the natural sciences; and (2) of distinguishing between behavioral sciences and social sciences.

Sociology is often called the science of society. In contrast to anthropology, sociology has always concentrated on the structure and functioning of groups within literate societies. Sociologists study such features of society as the family, rural and urban life, race relations, crime, and occupational groupings.[2]

Economics is the study of the allocation of scarce productive resources among competing uses. Within this framework, economists engage in theoretical and empirical research on micro-economic subjects-reaching and maintaining full employment, avoiding inflation and deflation, understanding and promoting economic growth, analyzing fiscal and monetary policies, defining balance and imbalance in international payments; also on micro-economic subjects - market pricing, monopolies, manpower, labor markets, union movements, farm issues, and problems resulting from inequalities in income distribution and poverty.

Psychology studies the nature and organization of mental processes in man. Psychologists deal with man's mental abilities and aptitudes, his capacities for learning, for thinking, for emotional expression, and for motivation. Psychologists have developed intelligence and aptitude tests for a great variety of uses. They work on problems of learning in education, problems of personnel selection in industry, and problems of clinical assessment in mental illness, among many others.

Political Science investigates the ways in which men govern themselves. It is concerned with the goals of the political system, the structural relationships in that system, the patterns of individual and group behavior which help explain how that system functions, and the policy outputs as well as behavioral consequences of that system. Political scientists study a variety of phenomena involved in the process of government, including political parties, interest groups, public opinion and communication, bureaucracy, international relations, and administration.

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[2] Social psychology is an important subfield that sociology shares with psychology. Social psychology studies the behavior of man as influenced by the groups to which he belongs.

APPENDIX B

PARTIAL LIST OF CONTRIBUTORS

Chemical Sciences

Jack B. Howard, MIT
I. Vink, MIT
William Peters, MIT
Michael Antal, Princeton University
Tom Reed, SERI
Tom Milne, SERI
Mel Bowman, LASL
John Norman, General Atomics
John Margrave, Rice University
Terry Cole, Ford Motor Corporation
Guy Elliott, LASL
Arthur Nozik, SERI
Norman Lichtin, Boston University
Norman Sutin, BNL
J. Kerry Thomas, Notre Dame
J. J. Katz, ANL
David Whitten, University of North Carolina
John S. Connolly, SERI
Arthur J. Frank, SERI

Biological Sciences

Biomass

Melvin Calvin, Berkeley
D. I. C. Wang, MIT
Charles Scott, ORNL
George Emert, Gulf Oil
John Benemann, Berkeley
Robert Inman, SERI
Ruxton Villet, SERI

Photobiology

J. R. Bolton, University Western Ontario
J. R. Benemann, Berkeley
R. K. Clayton, Cornell University
A. San Pietro, Indiana University
M. Seibert, P. Weaver, S. Lien, SERI

Material Sciences*

Metallurgy and Ceramics

John Wachtman, Director of Center for Materials Science, NBS and
President, American Ceramic Society
Joseph Pask, University of California
Benjamin Wilcox, Director of Materials Research, NSF
Dave Benson, SERI
Patrick Call, SERI
Thomas Coyle, SERI
Steven Pohlman, SERI

Materials Chemistry

Ernest Birchenall, University of Delaware
Jerome Kruger, NBS
David R. Miller, Monsanto
John M. Rusin, Battelle PNL
Albert Czanderna, SERI

Solid State Physics

Karl Boer, University of Delaware
S. Wagner, SERI
J. R. Burke, SERI
S. Deb, SERI
J. Stone, SERI
K. Mitchell, SERI
T. Surek, SERI
T. S. Jayadev, SERI

Engineering, Mathematics and Geosciences

Engineering

Sheldon Butts, Solar Energy Industries Association
Maria Telkes, American Technological University
Jack Duffie, University of Wisconsin-Madison
John Yellott, Yellott Solar Energy Labs
Don Neper, Los Alamos Labs
James Eibling, Battelle Memorial Institute
George Löf, Colorado State University and Solaron Corp.
Ari Rabl, SERI
Mark Bohn, SERI
Frank Kreith, SERI
T. S. Jayadev, SERI

Mathematics

Burton Wendroff, Los Alamos Scientific Laboratory
John Backmaster, Ohio State University
Gene Golub, Stanford University
Don Thompson, Society for Industrial and Applied Mathematics
Paul Davis, Consultants Computation Bureau

* More than 200 materials scientists participated in a solar materials workshop. Only a small portion are listed here.

Bill Kahan, University of California, Berkeley
Gary Hachtel, IBM Thomas J. Watson Research Center
Herb Keller, California Institute of Technology

Advanced Energy Projects

Roland Winston, University of Chicago
James Drummond, Power Conversion Technologies
T. S. Jayadev, SERI
John Connolly, SERI

Behavioral and Social Sciences

Political Science

Ronald Brunner, Inst. for Public Policy Studies, University of Michigan
Peter deLeon, SERI
Don Kash, U. S. Geological Survey
Todd LaPorte, Inst. of Governmental Studies, University of Calif., Berkeley
Edward Merrow, The Rand Corporation
Michael Mihalka, The Rand Corporation
Albert Teich, Technology and Public Program, The George Washington University
Jack White, Special Assistant to the Assistant Director for R&D, Environmental Protection Agency

Psychology/Social Psychology/Marketing

Paul Stern, Inst. for Social and Policy Studies, Yale University
Bruce Hutton, Asst. Professor of Marketing, University of Denver
Dennis McNeill, Asst. Professor of Marketing, University of Denver
C. T. Unseld, SERI
Barbara A. Burns, SERI

Sociology

Barbara Farhar, SERI
William F. Freudenburg, Asst. Professor of Sociology, Washington State University
Craig Piernot, SERI

Environmental Studies

John Holdren, Energy and Resources Group, University of California, Berkeley
Richard Caputo, Jet Propulsion Laboratory
Kathryn Lawrence, SERI

Economics

L. D. Chapman, Associate Professor, Cornell University
Anthony Fisher, Professor, University of California, Berkeley
Theresa Flaim, SERI
Timothy Mount, Associate Professor, Cornell University
Edward Kahn, Lawrence Berkeley Laboratory
H. Craig Peterson, Professor, Utah State University

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